



Solar Energy for Space Exploration Teacher's Guide

GRADE LEVEL: 6 to 12
SUBJECT: Physical Science

Solar Energy for Space Exploration

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Introduction

How does NASA (National Aeronautics and Space Administration) provide energy to the ISS (International Space Station)? How will NASA provide energy for research habitats on the Moon and Mars? In the 5-E model the NASA exploration context provides an exciting Engagement. During the Exploration and Explanation phases students learn about energy, power, electrical circuits and solar panels. The student investigations and design problems in **Solar Energy for Space Exploration** provide opportunities for Extension and Evaluation of fundamental concepts.

Solar Energy for Space Exploration is a problem-based learning activity (PBL). The culminating project requires students to propose and defend a design to provide power to a lunar or Martian research habitat for six explorers. To prepare for this final project, students will investigate the variables that affect the operation of solar panels, learn about energy, power, and circuits, design a solar energy system to meet the power requirements for their own homes, and learn about the solar panels and energy use on the ISS.

While understanding solar cells (or photovoltaic cells) is not included in National Science Education Standards, this short unit provides an exciting context for students to study energy, transfer of energy, electricity, and circuits—understanding of these concepts is required for students in grades five - eight. In addition, the context of providing solar energy for the ISS and for research habitats on the Moon and Mars provides an excellent way to introduce and reinforce the unique position of the Earth in the solar system. For older students, the study of photovoltaics can be an extension and a great way to demonstrate practical applications of many of the standards in Physical Science (Grades 9-12).

Objectives

1. Given solar cells or panels, students list variables that affect the operation of solar panels and explain how these variables affect the power production of solar panels.
2. Through computer simulations and laboratory investigations with electricity, students create parallel and series circuits, calculate power, and apply this knowledge to solve a theoretical problem on the ISS.
3. By analyzing the power requirements of their own homes, students design a solar system that could supply the power to their home.
4. Using the ISS as a model, students propose and defend a design to provide power for a lunar or Martian research habitat for six explorers.

Mastery of these objectives will depend on classroom expectations. Teachers are encouraged to develop rubrics and levels of mastery consistent with requirements.

Unit Overview

This unit is structured as a problem-based learning (PBL) activity. There are five student sections to the PBL—an introduction and four activities. For your convenience, a brief description of each section is provided below. Web resources are also shown below. Student handouts are available in the **Student Assignment Pages** and **Student Resources** sections. **Teacher Notes** provide specific information for each activity when necessary and are provided in **Preparation and Procedures** section. The **Teacher Resource** section at the end of the document contains resources for additional information and Standards.

1. Introduction: Scenario and Problem (15 minutes)

This page provides the challenge for the students.

- **Solar Energy for Space Exploration** – student handout

2. Investigating Solar Cells (two or three 45-minute periods)

In this investigation, students will learn about solar cells and what variables affect their operation.

- **Activity 1: Investigating Solar Cells - Journal Assignment** – student handout
- **Activity 1: Investigating Solar Cells - Investigation A** – student handout
- **Activity 1: Investigating Solar Cells - Investigation B** – student handout

3. Electricity and Power (3 –4 weeks)

Students will do the core concept development and meet core proficiencies in this section. Through computer simulations and laboratory work with electricity, students will learn about electricity, circuits, and power and apply this knowledge to solve a problem on the ISS.

- **Activity 2: Electricity and Power** – student handout
- **Electricity and Power in Space** - <http://iss.cet.edu/electricity/default.xml>

4. Solar Power for Your Home (three to four 45-minute periods)

Students will analyze the power requirements for their homes and propose designs that will use solar panels to supply all of the energy needs. Work may be done in small groups or individually.

- **Activity 3: Solar Power for Your Home** – student handout
- **Surface Meteorology and Solar Energy** - <http://eosweb.larc.nasa.gov/sse/>
- **Solar Energy Technologies Program** –
<http://www1.eere.energy.gov/solar/photovoltaics.html>
- **Roofus' Solar and Efficient Home** - <http://www1.eere.energy.gov/kids/roofus/index.html>
- **Solar Power Basics** -
<http://www.solarelectricpower.org/index.php?page=basics&subpage=pv&display=>

5. Solar Energy for the Moon and Mars (two to three 45-minute periods)

Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS.

Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

- **Activity 4. Final Problem: Solar Energy for Moon or Mars** – student handout
- **Interview with a PHALCON** – student handout
- **Solar Arrays for the International Space Station** – student handout
- **Power to the Station** <http://liftoff.msfc.nasa.gov/news/2001/news-stationpower.asp>
- **Model Space Station – Power Loads and Assembly Sequence** – student handout
- **Building a Modular Space Station** –
http://www.nasa.gov/pdf/161864main_Build_a_Modular_Space_Station.pdf
- **The Inconstant Sun** – http://science.nasa.gov/headlines/y2003/17jan_solcon.htm
- **Measuring Solar Radiation** – http://son.nasa.gov/lawis/energy/problem/solar_constant.pdf

General Background

This section provides general background information. Teacher's Notes provide specific background information for each activity in the **Preparation and Procedures** section.

NASA uses several different technologies for providing energy for space exploration. Each technology meets the requirements for different types of exploration. For space exploration close to the Sun (near the inner planets—Mercury, Venus, Earth, and Mars), solar power with battery backup is often an optimal option. This PBL will explore the use of solar panels as a power source. In the process, students will learn core classroom concepts relating to energy, energy transformation, electricity, and circuits.

For this PBL, it isn't necessary for you or your students to understand the operation of solar cells (photovoltaics). However, you may find the background information on photovoltaics contained in Secondary Solar Energy Teacher Guide and the Secondary Solar Energy Student Guide produced by the NEED (National Energy Education and Development) Project helpful <http://www.need.org/curriculum.php>.

Solar cell technology is improving rapidly. The solar cells used on the ISS are about 12 percent efficient. Those developed for the Mars Rovers are about 26 percent efficient. Current solar cells have higher efficiency. The students will have to do some research to determine the efficiency. When NASA engineers plan a mission, they have to know all of the specifications for all of the components, and the components have to be space tested. Sizes, electrical characteristics, masses, and connections must be known at the beginning of the planning. Since a mission might take 10 years to plan and construct, equipment might be 10 or more years "outdated." Your students will have to work with the same restrictions. They will be required to use solar cells that are currently available. They will have to research current technology.

A number of variables affect solar cell operation. Students will brainstorm, predict, and test variables in **Activity 1: Investigating Solar Cells**. Let students discover—guide students; do not lecture.

The following background information will help you to guide students more effectively. The critical variables that affect solar cell performance—other than the efficiency of the cell itself—affect the intensity of light on the solar cell. There are several factors that affect intensity:

Blocking - Natural conditions can block solar radiation from reaching the solar cells. Earth's atmosphere can partially block incoming solar radiation. The amount of light reaching Earth above the atmosphere is about 1366 Watts per square meter. When the Sun is directly overhead at the Equator, the intensity of solar radiation reaching Earth's surface is between 800 and 1,000 Watts per square meter. On the Moon and on Mars, solar panels can be blocked by dust. It was expected that the solar panels on the NASA Mars Rovers would become covered with dust and cease to provide energy for the systems. A chance dust devil swept the panels clean. Dust devils occur frequently enough on Mars that Rover panels are kept relatively clean.

Angle - The angle between the Sun and the solar panel is critical. The intensity of light is measured in the Watts (power) per square meter. You can experimentally quantify how the angle changes the intensity. Hold a flashlight directly above a sheet of graph paper. The light source is at 90° to the paper. Count the number of squares illuminated. Keep the flashlight at the same distance from the paper, but tilt the flashlight so that it is at an angle to the paper. This represents a lower Sun angle. Count the squares illuminated again. More squares will be illuminated at the lower angle. The power of the light stays the same, but the area lit increases as the angle gets lower. When the same amount of power is spread over a larger area, the intensity decreases. The 23.5° tilt of the Earth's axis determines the angle of sunlight. The Sun is overhead in June in the Northern Hemisphere at the Tropic of Cancer at 23.5° N. latitude. The Sun is overhead in January in the Southern Hemisphere at the Tropic of Capricorn at 23.5° S. The GEMS (Great Explorations in Math and Science) Guide, *The Real Reasons for the Seasons*, could be used during this lesson to help students to understand how the tilt of the Earth's axis affects the light intensity and the seasons. The axis of Mars is tilted at 25°, so very similar conditions prevail on Mars except the year is longer and each season is longer than Earth's. During the winter on Mars, the Rovers are parked on the slope of a hill to point the solar panels more directly at the Sun. As the International Space Station orbits Earth, the solar panels can be rotated to point more directly at the Sun. At times, the entire space station is pointed in a different direction to improve the angle of the panels and the Sun. For more information see *What are ISS Attitudes?* http://spaceflight.nasa.gov/station/flash/iss_attitude.html.

Distance from the Sun - As you know, the further you are from a light source, the dimmer (less intense) the light is. Students can confirm this experimentally and discover that the intensity (I) of light is inversely proportional to the square of the distance (r) from the light source ($I \propto 1/r^2$). You will need a light bulb, a meter tape measure, and a light intensity probe. In a dark room, measure the intensity of light at 10 cm, 20 cm, 40 cm, and 80 cm from the light. Plot Intensity versus distance. If you plot this curve on a graphing calculator, you can also obtain the equation for the curve.

The intensity decreases because the light spreads out farther away from the source. The Sun emits light energy in all directions. The light of the Sun is spread out over the surface of an imaginary (hollow) sphere with its center at the Sun. The farther the sphere is from the Sun, the bigger the sphere is and the more surface it has (surface area of a sphere = $4\pi r^2$). So, the power (energy per second) emitted by the Sun as light spreads over the surface of this imaginary sphere. Close to the Sun, the sphere is small. There is a lot of power per square meter (Intensity). Farther away, the sphere is big. There is less power per square meter. There is an equation that lets us calculate the intensity of light at a distance from a light source. The equation is:

$$\text{Intensity} = \text{Power}/(4\pi r^2)$$

But how can you measure the power of the Sun at its source? You can't. However, scientists have measured the intensity of light at Earth, and we know the distance from the Sun to Earth. The intensity of sunlight outside the Earth's atmosphere is 1366 Watts/m² (It varies from slightly with solar output). The distance (r) from the Sun to Earth is 150,000,000 km (kilometers). If you substitute these values into the equation above and solve for Power, the value for the power of light from the Sun is 384.6×10^{24} Watts (Joules/second).

Now we can use this value for Power in the equation above and calculate the intensity of light at Mars. The average distance from the Sun to Mars is 227,900,000 km. You can calculate that the intensity of light at Mars is 589.2 W/m². That is less than half of the intensity at Earth!

But wait! The orbit of Mars is less circular than Earth's orbit. It is more elliptical. At perihelion (closest to the Sun), Mars is 206,600,000 km away from the Sun, and the intensity is calculated to be 717.1 W/m². At aphelion (farthest from the Sun), Mars is 249,200,000 km away from the Sun, and the intensity drops to 492.9 W/m².

These differences could be significant to the design of a solar energy system.

You will have to judge whether your students will be able to understand the math involved.

The Planetary Fact Sheet (located at <http://nssdc.gsfc.nasa.gov/planetary/planetfact.html>) will provide additional information.

Preparation and Procedures

1. Introduction: Scenario and Problem (15 minutes)

- Download, print, and distribute **Solar Energy for Space Exploration**.

Procedure:

Have students read the scenario, challenge, and overview. Share with students the time line you have developed for this unit. Students may have procedural questions that can be answered at this time. If you begin this unit at the beginning of class, you will have time for students to complete **Activity 1: Investigating Solar Cells – Journal Assignment**.

2. Investigating Solar Cells (two or three 45-minute periods)

There are three parts to this activity: a Journal Assignment, Investigation A, and Investigation B. Each is described below.

Activity 1: Investigating Solar Cells - Journal Assignment.

See **General Background**.

- Download, print, and distribute **Activity 1: Investigating Solar Cells - Journal Assignment.**

Procedures

This writing assignment is designed to get the students to make predictions about the variables that might affect solar panels. Emphasize that you are looking for careful thought. There are a number of variables students might identify. There are no wrong answers. The purpose is to get students engaged in the process of the investigation. They will have opportunities to test their ideas. Following the journal assignment, a short class discussion in which students share their ideas may facilitate investigations.

Activity 1: Investigating Solar Cells - Investigation A

Materials per Group of Students

- | | |
|--|---|
| 1. solar cell | 6. black marking pen |
| 2. small electric motor | 7. stopwatch |
| 3. 10-inch pie round (25.4 cm stiff cardboard disk | 8. black construction paper |
| 4. plastic wheel that will fit over axle of motor | 9. red, green, and blue transparency film |
| 5. glue | 10. electrical wire to connect solar cell and motor |

Teacher's Notes

The experimental design provides a direct connection between energy and work. The solar energy is converted into electrical energy. The electrical energy is transformed into mechanical energy in the motor. As the axle in the motor turns, it turns a disk attached to the axle. The mechanical energy of the motor is transformed into kinetic energy (rotational) of the disk. Students should have studied work and kinetic energy and should be able to understand that the greater the speed of the disk, the greater the kinetic energy the disk will have.

Many physical science supply companies supply solar cells and electric motors. Try to find motors that have low rpm (revolutions per minute). If the motor turns too fast, students won't be able to count the revolutions. If the only motors you can find turn too fast for students to count the revolutions per minute, you can add a 5 k Ω (kilo-ohm) potentiometer in series in the circuit and use the potentiometer as a rheostat (like the rheostats used as light dimmers).

Instructions for making this modification can be found at *All About Circuits*
http://www.allaboutcircuits.com/vol_6/chpt_3/7.html.

Another option is to use the motor to lift a mass against the force due to gravity. Attach a small pulley wheel to the axle and wind a length of string around the wheel. Attach the other end of the string to a known weight. The motor should pull the weight upward at a constant rate of about 0.5 meters per second. Power is defined as work/time. Work can be calculated using the simplified formula $W = \text{force} \times \text{distance}$. In this case, the force is the weight of the mass (in N [Newton's]), and the distance is the vertical distance the mass is raised. You will have to experiment with your solar cells and motor to determine the best weight and distance.

You could also measure the power output from the solar cell directly. Power for an electrical circuit is equal to the voltage times the current ($P=V \times I$). The Secondary Solar Energy resource, located in the Teacher Resources section, provides an experimental procedure. This is a more difficult idea for students to understand.

Have students think carefully about the experimental procedure in this investigation. The transparent films also decrease the intensity of light. Does each film decrease the intensity by the same amount? Also, the red film blocks green and blue light very well. Most green films block blue light well, but do not block red light completely. Blue films usually allow some green and red light to pass.

Procedures and questions shown below are provided on the student pages that you can download.

➤ Download, print, and distribute **Activity 1: Investigating Solar Cells - Investigation A.**

Procedure

1. Attach the plastic wheel to the shaft of the motor.
2. Make a small dot on the edge of the cardboard disk.
3. Glue the cardboard circle to the wheel so that it will rotate when the motor is turning.
4. Attach the solar cell to the motor. Follow the teacher's instructions.
5. Place the solar cell and motor in bright sunlight. The motor should cause the cardboard disk to spin. If no spinning occurs, check the connections.
6. Watch the dot on the cardboard disk. Start the stopwatch as the dot gets to the top. Count the number of times the cardboard disk spins in 15 seconds. Multiply this number by four to get the number of revolutions per minute. Record this information.
7. Cover half of the solar cell using the piece of black construction paper. Repeat Step 6.
8. Cover approximately one-fourth of the solar cell with the construction paper. Repeat Step 6.
9. Cover the solar cell with one piece of the red transparency film. Repeat Step 6, and record the data.
10. Repeat Step 9 with each of the different colors of transparency film.

Questions (students will answer these questions after doing the investigation)

1. What happened when you covered part of the solar cell with black paper? Why?
2. What is the relationship between the amount of solar cell that is covered and the speed at which the disk turned? Explain.
3. How is the speed of the disk related to the energy provided by the solar cell?
4. How did the colored transparencies affect the solar cells ability to function?

Activity 1: Investigating Solar Cells - Investigation B

See **Teacher's Notes** for Investigation A.

- Download, print, and distribute **Activity 1: Investigating Solar Cells - Investigation B**.

Procedures

Have a variety of materials on hand. You will need all of the materials used in Investigation A. Also provide protractors, metric rulers, and perhaps fine sand or finely ground volcanic rocks used for landscaping as Mars or Moon soil simulant. You may wish to perform a Web search for Mars or Moon soil simulant. The discussion following the journal assignment will alert you to the types of materials you will need. The students are required to design their own experiment, so they may think of other materials to use. You should review their experimental design to ensure safe procedures before they begin. Also, provide your usual lab report format/rubric/documents.

3. Electricity and Power (3 –4 weeks)

Students will develop the core concepts and meet core proficiencies in this section. It is recommended that you use **Electricity and Power in Space**, which is located at <http://iss.cet.edu/electricity/default.xml>. This online program developed by the Classroom of the Future offers an excellent blend of hands-on activities, computer simulations, and a problem-solving context that is standards-based and addresses students' common preconceptions. Through computer simulations and laboratory work with electricity, students will learn about electricity, circuits, and power and apply this knowledge to solve a problem on the ISS. If you choose to do the online activities, you should review the materials required before assigning the activities. The unit requires computers. Students can work in small groups of two to three.

You know the standards you are required to meet. Examine the online unit. If **Electricity and Power in Space** is more or less rigorous than your requirements, you may wish to supplement your own activities. You can adjust requirements in later activities.

- Download, print, and distribute **Activity 2: Electricity and Power**.

Teacher's Notes

Provided at **Electricity and Power in Space** Web site.

Procedures

Provided at **Electricity and Power in Space** Web site.

4. Solar Power for Your Home (four to five 45-minute periods)

Students will analyze the power requirements for their homes and propose a design that will use solar panels to supply all of their energy needs.

Teacher's Notes

The ultimate goal for the “Solar Energy for Space Exploration” activity is to propose a design for a solar energy system that will provide energy for a research habitat for six researchers on the Moon or Mars. But it is easier to start with an environment the students know. Designing a solar energy system for their own homes lets students start with an environment they know well. However, they will still need to examine current electric bills and do additional research. Many homes don't provide all of their energy needs with electricity. It may be necessary to call local appliance providers or estimate electrical requirements. For this challenge, students are required to provide all of the energy from the solar panels. This is to prepare them for the problems of designing for a lunar or Martian research habitat. NASA will not be able to provide a local power grid on the Moon or Mars for a long time.

Students need to examine peak power demands for their home, and they need to examine peak and low solar energy availability. In cold, northern regions heating demands may peak just when solar availability is lowest. Remember, the task is to provide all energy demands with solar energy. So, even if their current homes are burning wood, pellets, or oil to provide heat during winter months, they must find out how much energy is required and how they can supply the energy with electric appliances. They can research electrical heating systems, and find the average energy usage.

Also, the solar angle can be critical. If the panels are fixed in place, then the season and the angle of the Sun can be critical.

The number of hours of sunlight can be important. Batteries can help to supply energy during the night. Many Earth-bound applications of solar cells use a dual source of electrical energy. Most homes get electrical energy from the local power grid. The local power grid gets electrical energy from coal burning, hydroelectric, or nuclear power plants. Most solar homes receive electricity from the solar panels and are connected to the local power grid. When the solar panels are producing more energy than a home can use, the excess is ‘pumped out’ to the grid, and the homeowner receives credit. When the home cannot get enough electrical power from the solar panels (at night or during cloudy periods), the local power grid supplies what is needed.

Designing a home solar energy system that supplies all energy needs can be a difficult problem. You need to establish the degree of rigor you will require—and this may affect the amount of time you wish to dedicate to this part of the unit. And, you will need to have some flexibility the first few times you run this activity. Some of your requirements will depend on the depth of the previous activity. If you examined circuits and power requirements and did circuit calculations, you will want students to look at appliances in their houses and their power requirements. If you did not go into much depth in the study of circuits and power, the average monthly usage reflected in electric bills may be sufficient. Realize that this activity may highlight the differences in economic levels in your student population.

This activity also provides an excellent opportunity to have students examine and discuss the sustainability of their practices over long periods of time. Does wood burning or pellet stoves

contribute significantly to air pollution? Can we continue to burn oil for heat? Does the cost of solar power create an economic barrier and seriously penalize the poor? Is conservation of energy important?

➤ Download, print, and distribute **Activity 3: Solar Power for Your Home**.

Procedure

Designing a home solar energy system requires creative problem solving. There are no definite procedures, but there are some guidelines students may find helpful:

- Find out what you already know.
- Think and talk about in your design groups what you want to learn.
- Do research and record what you learn so you can use it in your design.

The following questions may be helpful in guiding students:

- What are the power requirements for your home?
- Are the power requirements constant, or do they vary during the day and during the year?
- How much solar energy is available where your home is?
- Does the amount of available solar energy change during the day and during the year?
- What can you do if your solar panels produce more energy than your home requires?
- What happens if your solar panels don't provide enough energy for short periods?

Resources

➤ □ Surface Meteorology and Solar Energy (<http://eosweb.larc.nasa.gov/sse/>)

This NASA site provides you with information about the amount of solar energy available throughout the year where you live. Students will need access to computers. Students must look at the available information and decide what information they need. You will need to become familiar with the site before the activity so you can guide your students depending on the level of rigor you require.

- Click on Meteorology and Solar Energy.
- Get data tables for a particular location either by selecting "Click on a desired map location" or by "Enter latitude and longitude." (It is easier to use this site if you have your latitude and longitude.)
- Register by using student e-mail address and a password the student creates. This is secure and will not lead to unwanted e-mails. You may wish to use your e-mail and a common password for all students.
- If you chose to find your location with a map, click on the image of the globe to center it near your location, and choose zoom levels. You will probably have to center and zoom a few times. If you chose to use latitude and longitude, type in the correct values.
- When you select a location, you will get options for data. Until you know what you need, click Submit. This will give you all of the data.

Additional Internet Resources

- Solar Energy Technologies Program
<http://www1.eere.energy.gov/solar/photovoltaics.html>
- Roofus' Solar and Efficient Home
<http://www1.eere.energy.gov/kids/roofus/index.html>
- Solar Power Basics
<http://www.solarelectricpower.org/index.php?page=basics&subpage=pv&display=>

5. Challenge: Solar Energy for Moon and Mars (two to three 45-minute periods)

Working in small groups, students will choose either the Moon or Mars as the location for a NASA research habitat. Each group will estimate the requirements for the research habitat using what is known about home power requirements and the power requirements for the ISS. Then, each group will propose a design for a solar energy system to meet the energy requirements. This activity could be used as an assessment.

Teacher's Notes

The **General Background** section provides most of the general information you need. Additional background information is provided for you and your students in the files and Web resources in the links below.

- Download, print, and distribute **Activity 4. Final Problem: Solar Energy for Moon or Mars.**
- Download, print, and distribute **Interview with a PHALCON.**
- Download, print, and distribute **Solar Arrays for the International Space Station.**
- **Power to the Station** <http://liftoff.msfc.nasa.gov/news/2001/news-stationpower.asp>
- **Model Space Station – Power Loads and Assembly Sequence**
- **The Inconstant Sun** http://science.nasa.gov/headlines/y2003/17jan_solcon.htm
- **Measuring Solar Radiation** http://son.nasa.gov/lawis/energy/problem/solar_constant.pdf.

This activity could be made more robust by providing more information about the Moon or Mars. The **Student Observation Network** <http://son.nasa.gov> inquiry module, *Living and Working Safely on the Moon*, provides an opportunity for students to learn about the Moon and lunar resources necessary for developing a research habitat on the Moon. The **Mars Student Imaging Project** <http://msip.asu.edu/> allows students to discover Mars. **Imagine Mars** <http://imaginemars.jpl.nasa.gov/index2.html> is a multidisciplinary activity that allows students to think more broadly about developing a community on Mars. **Marsbound** <http://marsbound.asu.edu/> is a great game that engages students in developing a mission to explore Mars that can enrich their exploration of **Solar Energy for Space Exploration**.

Procedure

Designing a solar energy system for the Moon or Mars requires creative problem solving. There are no definite procedures, but there are some guidelines students may find helpful:

- Find out what you already know.
- Think and talk about in your design groups what you want to learn.
- Do research and record what you learn so you can use it in your design.

The following questions may be helpful in guiding students:

- What are the power requirements for your home?
- What are the power requirements for ISS?
- How might the power requirements for six researchers for an extended period of time be different?
- Are the power requirements constant or do they vary during the day and during the year?
- How much solar energy is available where your research habitat is?
- Does the amount of available solar energy change during the day and during the year?
- What can you do if your solar panels produce more energy than your research habitat requires?
- What happens if your solar panels don't provide enough energy for short periods?

Design Solution to Problem

Students should now have sufficient information to be able to work as a group to design the solar energy system for a research station on the Moon or Mars. The group will have to agree on some assumptions. Make certain that their assumptions are clearly stated and reasonable considering what they know. The emphases should be on careful thinking and not a correct solution. Even scientists and engineers struggle with this problem. The group should be clearly required to support its design with evidence.

If a group of students chooses to design a solution for a research station on Mars, you may want them to consider the decrease in solar energy that reaches Mars because it is farther from the Sun than Earth is.

Provide clear instructions and a rubric to your students about the kind of presentation you want them to make. For example, you may require a written report, a poster presentation, or a PowerPoint presentation.

Answers to math questions at the end of **Solar Arrays for the International Space Station** are provided below.

Math Connections - Solutions

1. How much power does each solar cell produce?

Information:

- Scientists have measured the intensity of solar radiation at the space station as about 1366 W/m^2 .
- Each solar cell is about 12 percent efficient. This means each cell can convert about 12 percent of the energy from the Sun that falls on the cell into electric power.
- What is the area of each solar cell? Look in the text above.

Solution

Intensity of solar radiation x area of solar cell x efficiency = 1.05 W

2. Using the amount of power from each cell, how much power should two arrays produce? How does this answer compare with the information in this article?

Information:

Each array contains 32,800 solar cells.

Solution

Number of cells per array x number of arrays x 1.05 W (answer from #1) = 68,880 W. The value in the text is 64 kilowatts (64,000 W) from two arrays. Some values have been rounded and some efficiency is lost.

3. What is the efficiency of two arrays? Why might this be different from the efficiency of a solar cell?

Information you need to know:

- What is the intensity of solar radiation at the space station?
- What is the area of an array?
- What is the power output from two arrays?

Solution

Intensity of solar radiation x area of array x two arrays = 1,023,000W

Efficiency = power output from two arrays (64,000W) divided by 1,023,000W = about 6 percent

The difference arises because a significant part of the array is structural, holding the cells together and giving strength to the whole array. One must always be careful about given information. In this case, students need the total area of the solar cells. The area of a solar panel will include structural material. This really isn't a trick question. Students will often assume that the total surface of their habitat can be covered by solar cells, but some of the area must be dedicated to the structure of the solar panel.

National Aeronautics and Space Administration



Solar Energy for Space Exploration Teacher Resources



Standards

National Science Education Standards

Grades 5-8

1. Science as Inquiry (Std [Standard] A)
 - a. Abilities necessary to do scientific inquiry
 - b. Understanding about scientific inquiry
2. Physical Science (Std B)
 - a. Transfer of Energy
3. Earth and Space Science (Std D)
 - a. Earth in the Solar System
4. Science and Technology (Std E)
 - a. Abilities of Technological Design
 - b. Understanding about Science and Technology

Grades 9-12

5. Science as Inquiry (Std A)
 - a. Abilities necessary to do scientific inquiry
 - b. Understanding about scientific inquiry

Physical Science (Std B)

- c. Structure of atoms
- d. Structure and properties of matter
- e. Chemical reactions
- f. Motions and forces
- g. Conservation of energy and increase in disorder
- h. Interactions of energy and matter

6. Science and Technology (Std E)

- a. Abilities of Technological Design
- b. Understanding about Science and Technology

Five Es			
	Suggested Activity	What the Teacher Does	What the Student Does
Engage	<ul style="list-style-type: none"> • Demonstrate • Read • Write freely • Analyze a graphic organizer • Brainstorm 	<ul style="list-style-type: none"> • Creates interest. • Generates curiosity. • Raises questions. • Elicits responses that uncover what the students know or think about the concept/topic. 	<ul style="list-style-type: none"> • Asks questions such as, Why did this happen? What do I already know about this? What can I find out about this? • Shows interest in the topic.
Explore	<ul style="list-style-type: none"> • Perform an investigation • Read authentic resources to collect information • Solve a problem. • Construct a model. 	<ul style="list-style-type: none"> • Encourages students to work together without direct instruction from the teacher. • Observes and listens to the students as they interact. • Asks probing questions to redirect the students' investigations when necessary. • Provides time for the students to puzzle through problems. 	<ul style="list-style-type: none"> • Thinks freely but within the limits of the activity. • Tests predictions and hypotheses. • Forms new predictions and hypotheses. • Tries alternatives and discusses them with others. • Records observations and ideas. • Suspends judgment
Explain	<ul style="list-style-type: none"> • Analyze and explain • Support ideas with evidence • Formulate structured questions • Read and discuss • Provide teacher explanation • Conduct thinking-skill activities: compare, classify, and analyze errors 	<ul style="list-style-type: none"> • Encourages the students to explain concepts and definitions in their own words. • Asks for justification (evidence) and clarification from students. • Formally provides definitions, explanations, and new labels. • Uses students' previous experience as basis for explaining concepts. 	<ul style="list-style-type: none"> • Explains possible solutions or answers to others. • Listens officially to others' explanations. • Questions others' explanations. • Listens to and tries to comprehend explanations the teacher offers. • Refers to previous activities. • Uses recorded observations in explanations.
Extend	<ul style="list-style-type: none"> • Solve problems • Make decisions • Conduct experimental inquiry • Conduct thinking-skill activities: compare, classify, and apply 	<ul style="list-style-type: none"> • Expects the students to use formal labels, definitions, and explanations provided previously. • Encourages the students to apply or extend the concepts and skills in new situations. • Reminds students of alternative explanations. • Refers the students to existing data and evidence and asks, "What do you already know?" "Why do you think?" • Strategies for explore apply here also. 	<ul style="list-style-type: none"> • Applies new labels, definitions, explanations, and skills in new but similar situations. • Uses previous information to ask questions, propose solutions, make decisions, and design experiments. • Draws reasonable conclusions from evidence. • Records observations and explanations. • Checks for understanding among peers.
Evaluate	<ul style="list-style-type: none"> • Do any of the above • Develop a scoring tool or rubric • Test • Assess performance • Produce a product • Make a journal entry • Create a portfolio 	<ul style="list-style-type: none"> • Observes the students as they apply new concepts and skills. • Assesses students' knowledge and/or skills • Looks for evidence that students have changed their thinking or behaviors • Allow students to assess their own learning and group-process skills. • Asks open-ended questions, such as: Why do you think? What evidence do you have? What do you know about x? How would you explain x? 	<ul style="list-style-type: none"> • Answers open-ended questions by using observations, evidence, and previously accepted explanations. • Demonstrates an understanding or knowledge of the concept or skill. • Evaluates his or her own progress and knowledge. • Asks related questions that would encourage future investigations.



Solar Energy for Space Exploration Student Assignments



ISS, Moon, Mars, and Beyond

Scenario

Humans like to explore. NASA's mission over the next few decades is to explore the Moon and Mars. Living and working on the ISS (International Space Station) is a vital steppingstone to future exploration of space. By going to the Moon for extended periods of time, astronauts will search for resources and learn how to work safely in a harsh environment. The Moon also offers many clues about the time when the planets were formed. Robotic missions to Mars have found evidence of a watery past. This suggests that simple life forms may have developed long ago and may persist beneath the surface today. Human exploration of Mars could provide answers to some important questions. Humans and robots will work together exploring the Moon and Mars. Meanwhile, NASA spacecraft will continue to send scientific data from throughout the solar system. This will lay the groundwork for potential human journeys. But how will NASA provide energy for extended research on the Moon or on Mars? Solar panels with batteries seem to be the best option.

Challenge

Propose a design using solar panels that will supply the energy requirements for a research habitat on the Moon or on Mars. Assume there will be a research crew of six humans and current technology will be used for solar panels.

Overview

You will need background knowledge to design a good solar energy system for exploration of the Moon or Mars. These investigations and activities will help you learn what you need to know.

1. Investigating Solar Cells

You will learn about solar cells and what variables affect their operation.

2. Electricity and Power

You will learn about electricity, circuits, and power and use this knowledge to solve a problem on the ISS.

3. Solar Power for Your Home

You will analyze the power requirements for your home and propose a design that will use solar panels to supply all of your needs.

4. Challenge: Solar Energy for Moon and Mars

Choose either the Moon or Mars as the location for your research habitat. From what you know about your home power requirements and the power requirements for ISS, estimate the requirements for your research habitat. Then, propose a design for a solar energy system to meet the energy requirements.



Activity 1. Investigating Solar Cells: Journal Assignment

The Sun radiates, or sends out as light, an enormous amount of energy. The Sun radiates more energy in one second than people have ever used. Only a small part of the radiant energy produced by the Sun strikes the Earth. Yet, every day enough solar energy strikes the United States to supply the energy needs of the United States for about one and a half years. Much of the energy is reflected back into space, evaporates water, or is absorbed by plants, land and water. This still leaves enough to supply our energy needs. Some solar energy is used to heat water, homes, or other buildings. Solar cells can change solar energy into electrical energy.

Answer the following question in your journal as completely as you can. Your entry will be evaluated on the thoughtfulness of your answers and the reasoning you give in support of your answer.

What factors (variables) might affect how much electrical energy a solar cell could produce?



Activity 1. Investigating Solar Cells: Investigation A

Will different colors of light affect how much electrical energy a solar cell will produce?

Purpose

This investigation will allow you to explore one of the variables that might affect how much energy a solar cell can produce. A solar cell will provide energy for a small electric motor to do work. The motor will turn a disk. More energy will make the motor and the disk turn faster. By covering the solar cell with different colored transparent films, you can test whether one color of light provides more energy to the solar cell.

Materials per Group of Students

- | | |
|--|---|
| 1. solar cell | 6. black marking pen |
| 2. small electric motor | 7. stopwatch |
| 3. 10-inch pie round (25.4 cm stiff cardboard disk | 8. black construction paper |
| 4. plastic wheel that will fit over axle of motor | 9. red, green, and blue transparency film |
| 5. glue | 10. electrical wire to connect solar cell and motor |

Procedure

1. Attach the plastic wheel to the shaft of the motor.
2. Make a small dot on the edge of the cardboard disk.
3. Glue the cardboard circle to the wheel so that it will rotate when the motor is turning.
4. Attach the solar cell to the motor. Follow the teacher's instructions.
5. Place the solar cell and motor in bright sunlight. The motor should cause the cardboard disk to spin. If no spinning occurs, check the connections.
6. Watch the dot on the cardboard disk. Start the stopwatch as the dot gets to the top. Count the number of times the cardboard disk spins in 15 seconds. Multiply this number by four to get the number of revolutions per minute. Record this information.
7. Using the piece of black construction paper, cover half of the solar cell.
Repeat Step 6.
8. Cover approximately one-fourth of the solar cell with the construction paper.
Repeat Step 6.
9. Cover the solar cell with one piece of the red transparency film. Repeat Step 6, and record the data.
10. Repeat Step 9 with each of the different colors of transparency film.

Questions

1. What happened when you covered part of the solar cell with black paper? Why?
2. What is the relationship between the amount of solar cell that is covered and the speed at which the disk turned? Explain.
3. How is the speed of the disk related to the energy provided by the solar cell?
4. How did the colored transparencies affect the solar cells ability to function?



Activity 1. Investigating Solar Cells: Investigation B

How do other variables affect how much electrical energy a solar cell will produce? Design your own experiments to investigate as many variables as you can.

Purpose

These experiments will help you to understand how design the most effective solar panel system.

Procedure

1. Create a list of three to five variables that might affect how much electrical energy a solar cell will produce.
2. Design an experimental procedure to test each variable. If you have three variables, you will have three different procedures.
3. Perform each experiment and record the data.
4. Make a conclusion about what variables affect solar cells.



Activity 2. Electricity and Power

Through computer simulations and laboratory work with electricity, you will learn about electricity, circuits, and power and apply this knowledge to solve a problem on the ISS.

Procedure

Go to Web site *Electricity and Power in Space* <http://iss.cet.edu/electricity/default.xml> and follow directions.



Activity 3. Solar Power for Your Home

Analyze the power requirements for your home and propose a design that will use solar panels to supply all of your needs.

Background

The ultimate goal for the “Solar Energy for Space Exploration” activity is to propose a design for a solar energy system that will provide energy for a research habitat for six researchers on the Moon or Mars. But it is easier to start with an environment you know. Designing a solar energy system for your home lets you start with an environment you know well.

Many Earth-bound applications of solar cells use a dual source of electrical energy. Most homes get electrical energy from the local power grid. The local power grid gets its electrical energy from coal burning, hydroelectric, or nuclear power plants. Most solar homes receive electricity from the solar panels and are connected to the local power grid. When the solar panels are producing more energy than a home can use, the excess is ‘pumped out’ to the grid and the homeowner receives credit. When the home cannot get enough electrical power from the solar panels (at night or during cloudy periods), the local power grid supplies what is needed.

For this challenge you are required to provide all of the energy from the solar panels. This is to prepare you for the problems of a design for a lunar or Martian research habitat. NASA will not be able to provide a local power grid on the Moon or Mars for a long time.

Procedure

This problem requires creative problem solving. There are no definite procedures, but there are some guidelines you may find helpful:

- Find out what you already *know*.
- Think and talk about in your design groups what you *want* to learn.
- Do research and record what you *learn* so you can use it in your design.

The following questions may be helpful in guiding you.

- What are the power requirements for your home?
- Are the power requirements constant, or do they vary during the day and during the year?
- How much solar energy is available where your home is?
- Does the amount of available solar energy change during the day and during the year?
- What can you do if your solar panels produce more energy than your home requires?
- What happens if your solar panels don’t provide enough energy for short periods?

Resources

Surface Meteorology and Solar Energy (<http://eosweb.larc.nasa.gov/sse/>)

This NASA site will provides you with information about the amount of solar energy available throughout the year where you live.

1. Click on Meteorology and Solar Energy.
2. Get data tables for a particular location either by selecting "Click on a desired map location" or by "Enter latitude and longitude."
3. Register by using your e-mail address and a password. This login is secure, and registration will not lead to unwanted e-mails.
4. If you chose to find your location with a map, click on the image of the globe to re-center near your location and choose zoom levels. You will probably have to re-center and zoom a few times. If you chose to use latitude and longitude, type in the correct values.
5. When you select a location, you will get options for data. Until you know what you need, click Submit. This will give you all of the data.

Additional Internet Resources

Solar Energy Technologies Program

<http://www1.eere.energy.gov/solar/photovoltaics.html>

Roofus' Solar and Efficient Home

<http://www1.eere.energy.gov/kids/roofus/index.html>

Solar Power Basics

<http://www.solarelectricpower.org/index.php?page=basics&subpage=pv&display=>



Activity 4. Final Problem: Solar Energy for Moon or Mars

Choose either the Moon or Mars as the location for your research habitat. From what you know about your home power requirements and the power requirements for the ISS, estimate the requirements for your research habitat. Then, propose a design for a solar energy system to meet the energy requirements.

First, find out about solar power and ISS. Find out how the power requirements of the ISS are met.

Background

The ISS is like a home—only it is isolated in space 330 to 390 kilometers above the Earth. It has electric appliances. Some of those appliances need to stay on. Some of the appliances can and should be turned off when the astronauts leave the room. The following resources will help you to understand how ISS gets the energy necessary to run all of the equipment and experiments and how much power the equipment needs. This information will help you to plan the research habitats for the Moon or Mars.

Procedure

Designing a solar energy system for the Moon or Mars requires creative problem solving. There are no definite procedures, but there are some guidelines you may find helpful:

- Find out what you already *know*.
- Think and talk about in your design groups what you *want* to learn.
- Do research and record what you *learn* so you can use it in your design.

The following questions may be helpful in guiding you:

- What are the power requirements for your home?
- What are the power requirements for ISS?
- How might the power requirements for six researchers for an extended period of time be different?
- Are the power requirements constant, or do they vary during the day and during the year?
- How much solar energy is available where your research habitat is?
- Does the amount of available solar energy change during the day and during the year?
- What can you do if your solar panels produce more energy than your research habitat requires?
- What happens if your solar panels don't provide enough energy for short periods?

Resources

(Your teacher will give you printed copies of # 1, 2, and 4. You can link to the Web resources directly.) Read and interpret the information carefully. Decide what is important to the problem you have to solve.

1. Interview with a PHALCON

Steven Johnson works in ISS Mission Control at Johnson Space Center in Houston, Texas. In this interview he discusses some important solar panel issues

2. Solar Arrays for the International Space Station

This short article shows pictures of solar cells, solar panels, and solar arrays and gives some basic information about the size and number.

3. Power to the Station (<http://liftoff.msfc.nasa.gov/news/2001/news-stationpower.asp>)

4. Model Space Station – Power Loads and Assembly Sequence

Find out the energy requirements for a model space station. This is a simplified version of the ISS.

5. The Inconstant Sun http://science.nasa.gov/headlines/y2003/17jan_solcon.htm

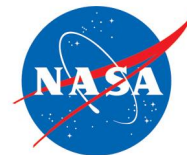
How much energy does the Sun provide? The Sun's intensity decreases as its energy spreads as it travels to Earth. The amount of energy at the outer atmosphere of Earth is called the solar constant, but it isn't totally constant.

6. Measuring Solar Radiation http://son.nasa.gov/lawis/energy/problem/solar_constant.pdf

This article discusses the solar constant and one mission to measure the changes in the solar constant.

Design Solution to Problem

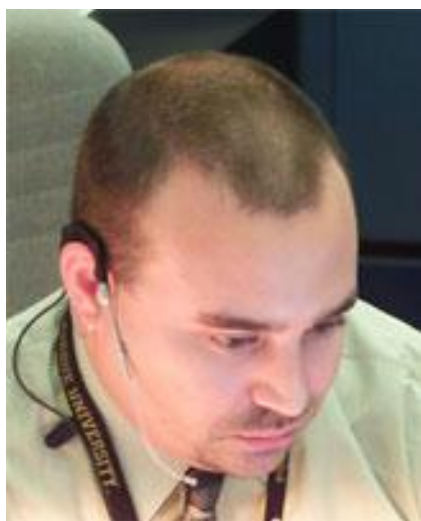
Now you should have enough information to design the solar energy system for a research station on the Moon or Mars. You will have to make some assumptions. What do you think those assumptions are? Make certain that your assumptions are clearly stated and reasonable considering what you know. Your solution will be evaluated on careful thinking, clear presentation, and support of your solution with evidence. Your teacher will give you requirements about the type of presentation you need to make.



Solar Energy for Space Exploration Student Resources



Interview with a PHALCON (Power, Heating, Articulation, Lighting and Control)



Steven E. Johnson is a mission control officer for the ISS. He works at NASA Johnson Space Flight Center in Houston, Texas. His flight control position is known as PHALCON. Mission Control operates most of the functions of the ISS from the ground in the Blue Flight Control Room. You can see an online map of the Blue Flight Control Room at <http://spaceflight.nasa.gov/station/reference/bluefcr/bfcr.html>. The PHALCON console is far forward and to the right. Move your cursor over the consoles to find out the job for each position.

The PHALCON team performed duties related to the docking of the 21st Progress vehicle with the ISS. Steven describes the mission below in an e-mail interview on Wednesday, April 26, 2006.

“The Progress spacecraft are unmanned Russian cargo vehicles. Progress 21 launched from the Baikonur Cosmodrome in Kazakhstan on April 24, 2006, at 12:03 p.m. e.d.t., (10:03 p.m. Baikonur time).

When the 21st Progress visited the ISS, it had just over 2.5 tons of equipment and supplies onboard. Included in its 5,040 pounds of cargo were more than 1,900 pounds of propellant, just over 100 pounds of air and oxygen, 661 pounds of water and almost 2,360 pounds of dry cargo.

The new Progress also has onboard some small crustaceans for a Russian scientific experiment called Aquarium onboard. That experiment focuses on the stability of closed ecological systems in microgravity. It could provide information useful for lengthy human spaceflights.

Progress 21 docked at the aft port of the Zvezda Service Module. Station crewmembers, Expedition 13 commander Pavel Vinogradov and NASA Science Officer Jeff Williams, opened the new arrival's hatch later in the day. While they might have sampled some of the fresh food aboard the Progress, they began unloading the Progress on Thursday.

As the power system controllers, PHALCON performed several activities related to the docking event. The inbound vehicle uses propulsion and attitude control thrusters to position itself. The thrusters can potentially spread fuel and oxidizer over the U.S. solar arrays. These contaminants can damage the solar array surfaces and decrease solar cell performance. To minimize the likelihood of damage, PHALCON positions the arrays so that the wide surface of the solar panels

is not facing the Progress thrusters. This 'edge-on profile' provides the smallest surface facing the thrusters. But, often, this means the solar panels aren't facing the Sun so they can't produce as much power.

The arrays are locked in a stationary position and, therefore, they are not tracking the Sun during rendezvous and docking. However, in today's instance, ISS power use was relatively low, and power generation in the stationary solar array position was exceptionally good. The above-average power generation was due to the orbit of ISS, which allowed the solar arrays to maintain an unshadowed line-of-sight to the Sun. Following the docking, the solar arrays were returned to automatic sun-tracking mode.

There is also some risk of damage to the solar arrays when a vehicle leaves the station. Progress 20 is already docked to ISS and is the sister cargo carrier to Progress 21. Progress 20 will remain at the Pirs Docking Compartment until mid-June. Progress 20 is being loaded with trash and surplus equipment from the station. It will leave the station without any crew and be placed in an orbit so that it will burn up after entry into the Earth's atmosphere.

Although the undocking vehicle uses mechanical springs instead of thrusters, PHALCON will still perform the same solar array activities to protect against contamination in case thruster firings are needed.

There are currently two solar array panels on the ISS. (Two more solar array panels were installed during the STS-115 mission in September, 2006.) There will be eight panels when assembly of the station is complete. Each panel contains 32,800 solar cells built into 82 strings. The strings are constructed in a combination of parallel and series electrical circuits. The parallel circuits allow power to be generated and charge batteries even if one string fails. (This is similar to how most Christmas light strings will allow most lights to remain lit even if one burns out.)

However, to increase the voltage, strings also have cells connected in series.

There is one bypass diode connected to every eight solar cells. These diodes allow cells in groups of eight to be bypassed if a cell fails or is in the shadow of some part of the station.

Therefore, damage or contamination of a group of solar cells or strings will not prevent the solar array from producing power. As one might suspect, damage of cells or strings reduces the amount of power the array can produce. The greater the extent of damage, the less power the solar array can produce.

All the solar cells and strings are not individually monitored from Mission Control. Therefore, we cannot tell if any given cell or string is damaged or degraded. However, through a solar array efficiency test, we can determine the approximate number of strings that are operating normally. We perform an efficiency test on each array about twice per year. A few years ago, we discovered that there is at least one failed string on one of the arrays. Using a video survey, we determined the failed string is a result of damage to the diode circuitry of the string. So, while the solar cells and the string itself may be functional, the diode that passes the power downstream is damaged. It's not likely the diode was damaged by thruster contamination. The damage is probably a result of flexing of the arrays or electrical arcing.

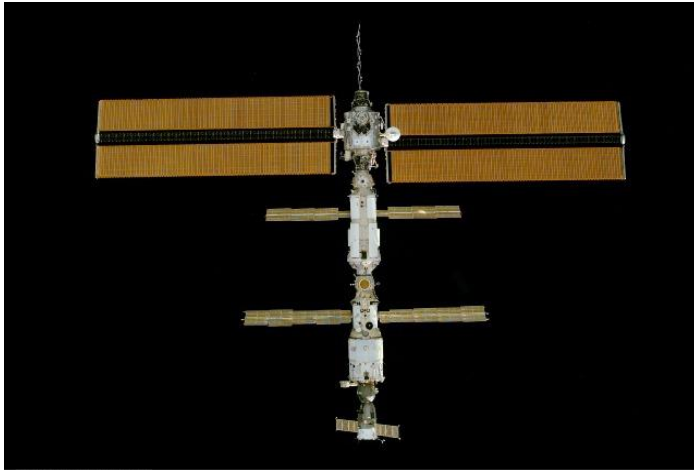
Individual cells, strings, and diodes cannot be replaced on orbit. Technically, the entire solar array can be replaced. However, this would be a major task, and would require significant EVA (Extra-

vehicular Activity), also known as a spacewalk. It would be a very complicated and expensive repair mission. Unfortunately, there are no spare solar arrays. We could use one of the six remaining solar array panels that are scheduled to be installed on later shuttle missions. However, without additional spare arrays (there are no plans or funds to build any more), the result would mean that we would still be without a solar array on a future mission. It is far cheaper and less risky to leave a failed solar array in place and continue with the normal schedule for adding new solar arrays.

When the ISS has its full complement of eight solar arrays (and to a lesser extent, when we have four active arrays), there is an electrical switching unit that allows power to be routed from one solar array to loads of another array. That is, the loads that are normally powered by a failed array can be powered from a functioning array. That allows PHALCON the flexibility to continue supporting ISS power demands even if one (or more) solar array completely fails.



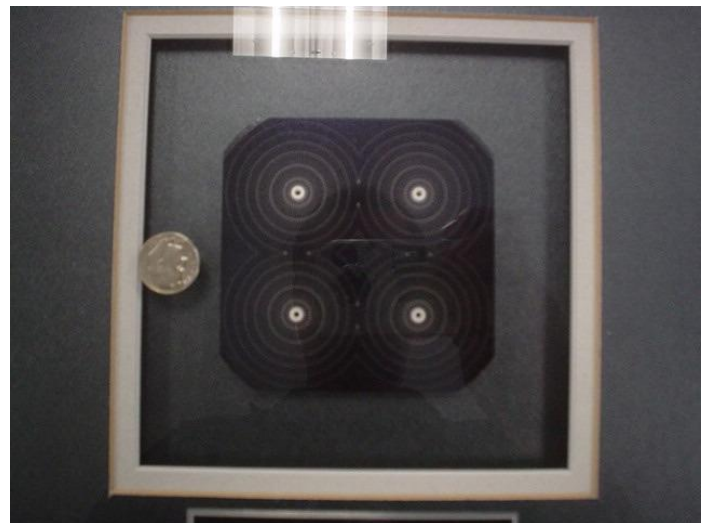
Solar Arrays for the International Space Station



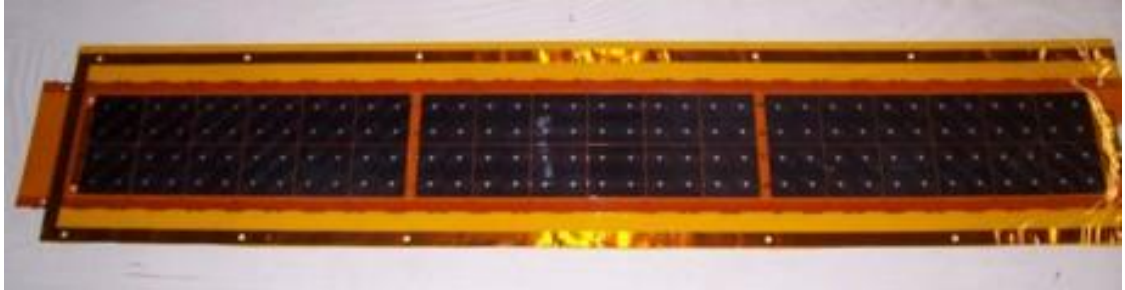
The ISS relies on huge solar panel arrays to convert solar energy into electrical power. The solar arrays are large, wing-like structures, each measuring 34 meters long and 11 meters wide (112 feet x 39 ft.). Since each array is extended in opposite directions, the total wingspan is over 73 meters (240 feet). Shown here are the two solar arrays installed by the shuttle crew of STS-97. These two arrays can supply nearly 64 kilowatts of power. This is enough to meet the needs of 30 average homes without air conditioning. The crew of STS-115 installed two additional arrays in September 2006. There will

be eight solar arrays when the space station is complete.

The image to the right shows an individual solar cell. It is about 8 centimeters (0.08 meters) square. Note the size of the dime next to the solar cell. The 8 eight arrays together will contain a total of 262,400 solar cells and cover an area of about 2,500 square meters (27,000 square feet) —more than half the area of an American football field!



The solar cells are electrically connected into solar panels. The panel shown below is similar to the solar panels on the station panel. As you can see, there are 36 solar cells making up this solar panel. This particular example is approximately 22.4 cm (57 inches) by 4.5 cm (11.5 inches).



In this close up image of the solar arrays used on the ISS, you can see many individual panels. Each panel has a border of white. If you look closely at the image, you can see that there are 40 individual cells in a panel. The panel is four cells wide and 10 cells long.

Math Connections

- How much power does each solar cell produce?

Information:

1. Scientists have measured the intensity of solar radiation at the space station as about 1,366 W/m².
 2. Each solar cell is about 12 percent efficient. This means each cell can convert about 12 percent of the energy from the Sun that falls on the cell into electric power.
 3. What is the area of each solar cell? Look in the text above.
- Using the amount of power from each cell, how much power should two arrays produce? How does this answer compare with the information in this article?

Information: Each array contains 32,800 solar cells.

- What is the efficiency of two arrays? Why might this be different from the efficiency of a solar cell?

Information you need to know:

1. What is the intensity of solar radiation at the space station?
2. What is the area of an array?
3. What is the power output from two arrays?



Model Space Station: Power Loads and Assembly Sequence

The ISS has appliances just like your home. The information provided here is for a simplified space station. For example, ISS will eventually have eight solar arrays. This model only has four solar arrays. The equipment that requires electrical power has been simplified somewhat, but the information will help you plan for a lunar or Martian mission.

The diagrams show what systems will be added as the construction of the space station proceeds.

The load is the electrical equipment that requires power. The power is measured in Watts (W). The equipment is usually on one of two circuits: Channel 1 (Ch 1) or Channel 2 (Ch 2).

Load	Power in Watts	Power Module 1		Power Module 2		Habitat Module		Command Module		Airlock		US Lab		Russian Lab		Japanese Lab & External Platform	
		Ch 1	Ch 2	Ch 1	Ch 2	Ch 1	Ch 2	Ch 1	Ch 2	Ch 1	Ch 2	Ch 3	Ch 4	Ch 3	Ch 4	Ch 3	Ch 4
Battery Unit	2215 W	3	3	3	3	-	-	-	-	-	-	-	-	-	-	-	-
Fan	535 W	-	-	-	-	1	1	1	1	1	-	-	1	1	-	1	-
Atmosphere Controller	1200 W	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Control System	820 W	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-	-	-
Crew System	575 W	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-	-	-
Comm Unit	470 W	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-	-	-
Lighting Bank	360 W	-	-	-	-	1	1	1	-	1	-	1	-	-	1	-	1
Canadian Robotic Arm	3210 W	-	-	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-
Robotic Workstation	895 W	-	-	-	-	-	-	1*	1*	-	-	-	-	-	-	-	-
Main Computer	385 W	-	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Air Pump	1150 W	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Experiment U.S. 1	4250 W	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Experiment U.S. 2	3005 W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Experiment U.S. 3	2275 W	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Experiment U.S. 4	2260 W	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Experiment R1	2715 W	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Experiment R2	3200 W	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Experiment R3	1845 W	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Experiment J1	1985 W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Experiment J2	920 W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Experiment J3	3460 W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
						* These components have one unit, but two separate power sources.											

This information can be broken down by channel. A channel is similar to a circuit in your house. The chart below shows the equipment and the power each uses on Channels 1 and 2.

Channel 1	#	Power in Watts	Net Power in Watts		Channel 2	#	Power in Watts	Net Power in Watts
Battery Unit	3	2,215	6,645		Battery Unit	3	2,215	6,645
Fan	3	535	1,605		Fan	3	535	1,605
Atmosphere Controller	1	1,200	1,200		Atmosphere Controller	1	1,200	1,200
Crew System	1	575	575		Crew System	1	575	575
Control System	1	820	820		Control System	1	820	820
Ccommunications	1	470	470		communications	1	470	470
Lighting Bank	3	360	1,080		Lighting Bank	3	360	1,080
Main computer	1	385	385		Main computer	1	385	385
Robotic Workstation	1	895	895		Robotic Workstation	1	895	895
Canadian Robotic Arm	1	3,210	3,210		Canadian Robotic Arm	1	3,210	3,210
Air pump	1	1,150	1,150		Air pump	1	1,150	1,150
		Total	18,035				Total	18,035

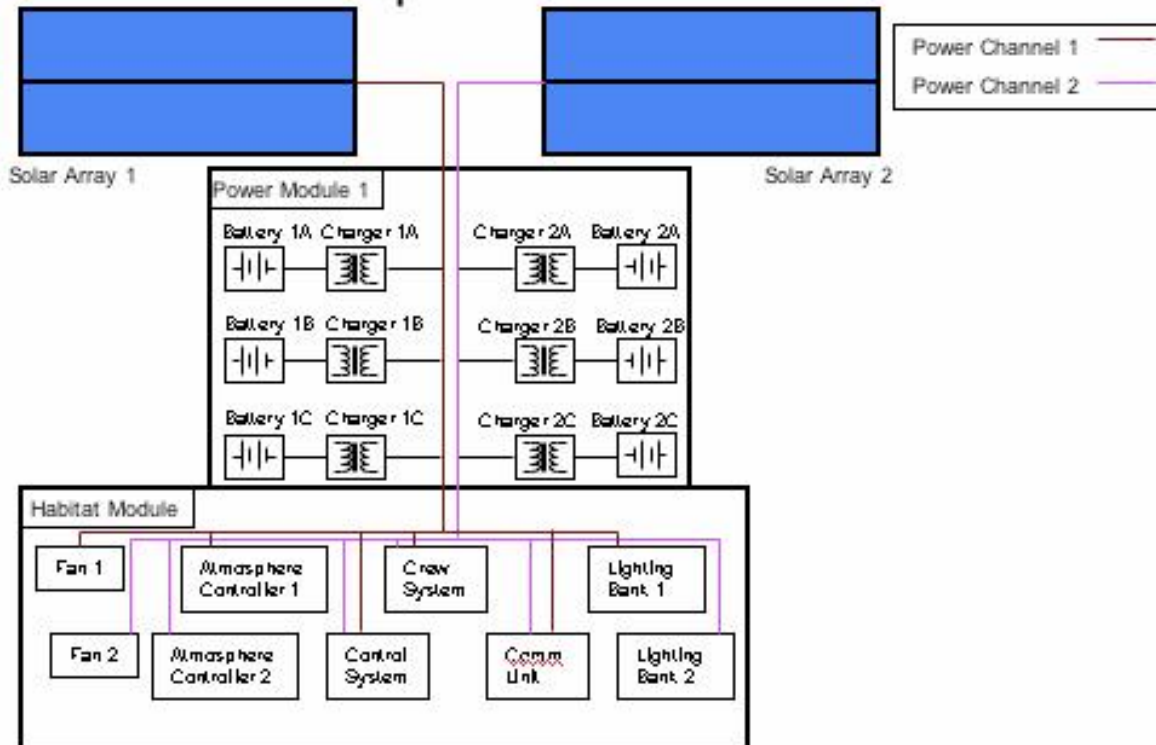
The chart below shows the equipment and the power each uses on Channels 3 and 4.

Channel 3	#	Power in Watts	Net Power in Watts		Channel 4	#	Power in Watts	Net Power in Watts
Battery Unit	3	2,215	6,645		Battery Unit	3	2,215	6,645
Fan	1	535	535		Fan	2	5,35	1,070
Lighting Bank	2	360	720		Lighting Bank	1	360	360
Experiment U.S. 1	1	4,250	4,250		Experiment US 2	1	3,005	3,005
Experiment U.S. 3	1	2,275	2,275		Experiment US 4	1	2,260	2,260
Experiment Russian 1	1	2,715	2,715		Experiment Russian 2	1	3,200	3,200
Experiment Russian 3	1	1,845	1,845		Experiment Japan 2	1	920	920
Experiment Japan 1	1	1,985	1,985		Experiment Japan 3	1	3,460	3,460
		Total	20,970				Total	20,920

The following pages show what equipment is added to the ISS at each stage of construction.

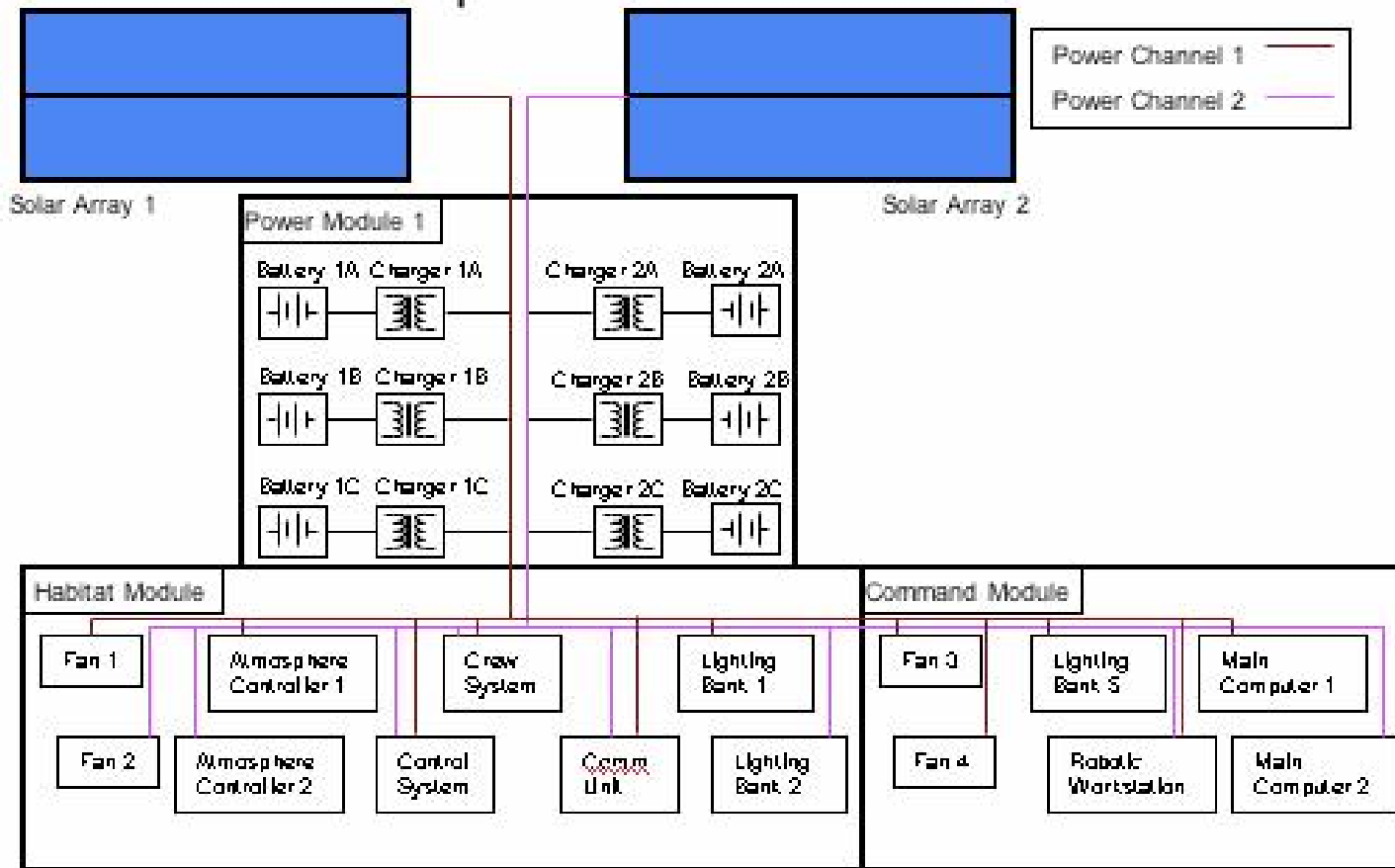
International Space Station

Stage 1



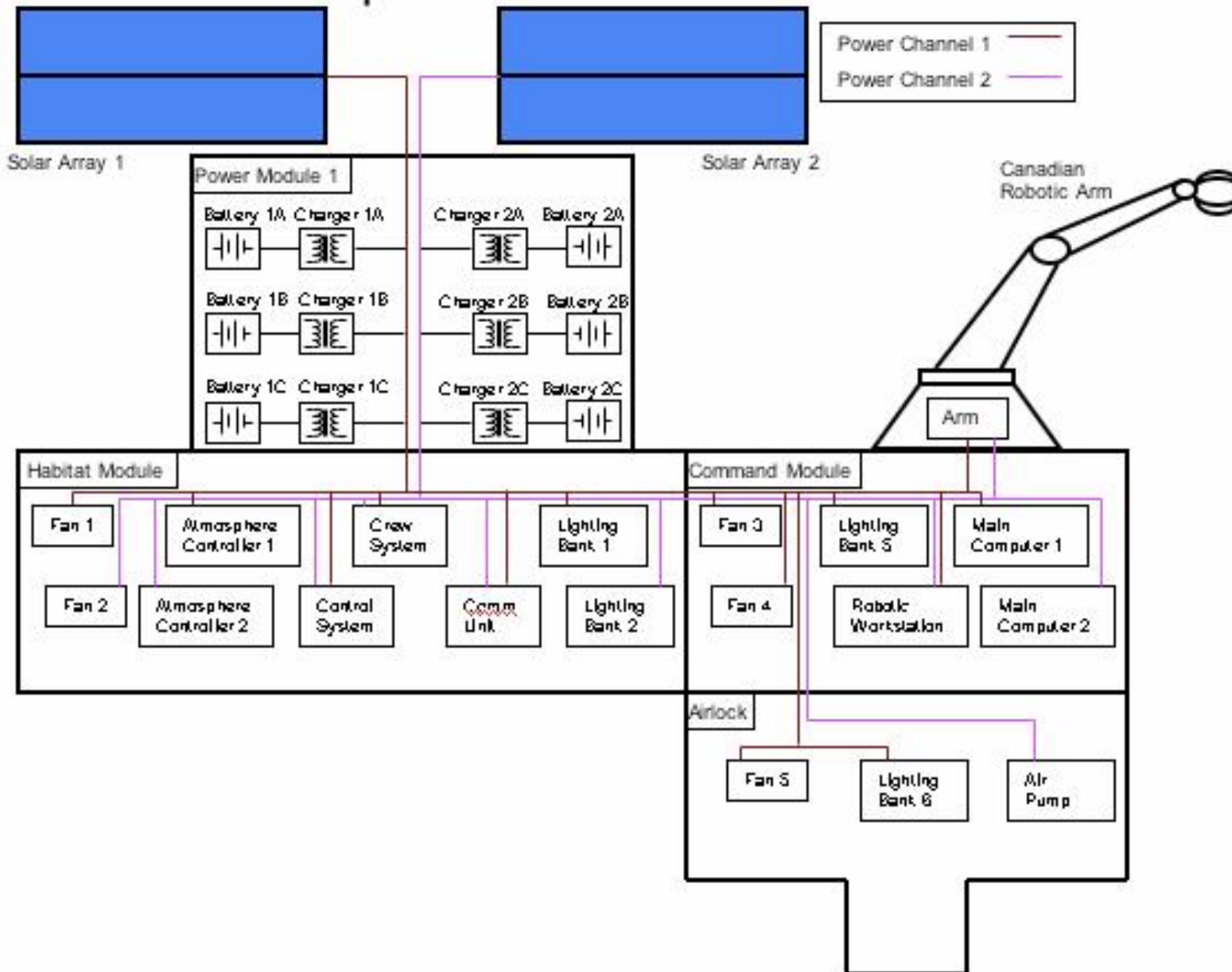
International Space Station

Stage 2



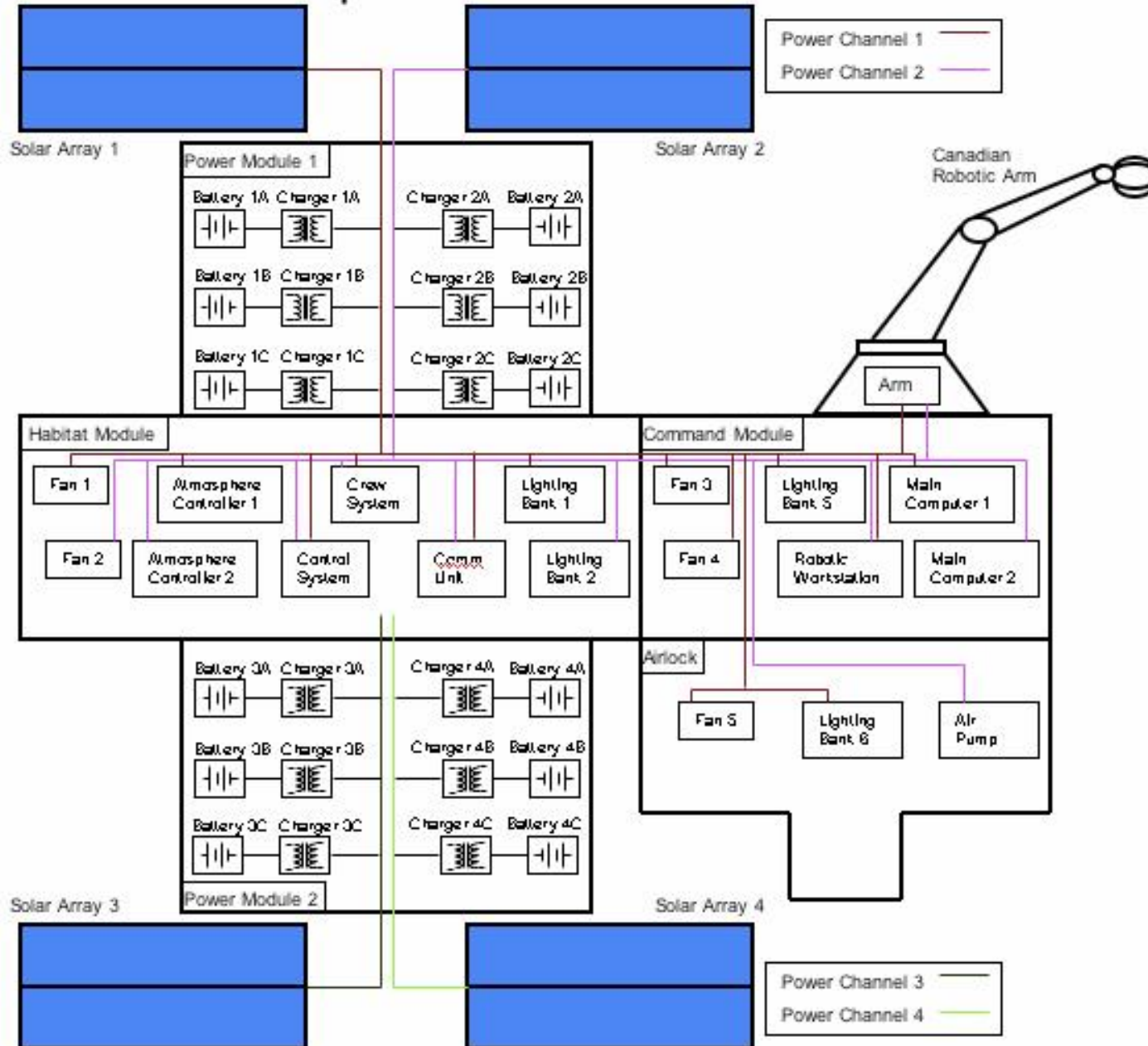
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Stage 3



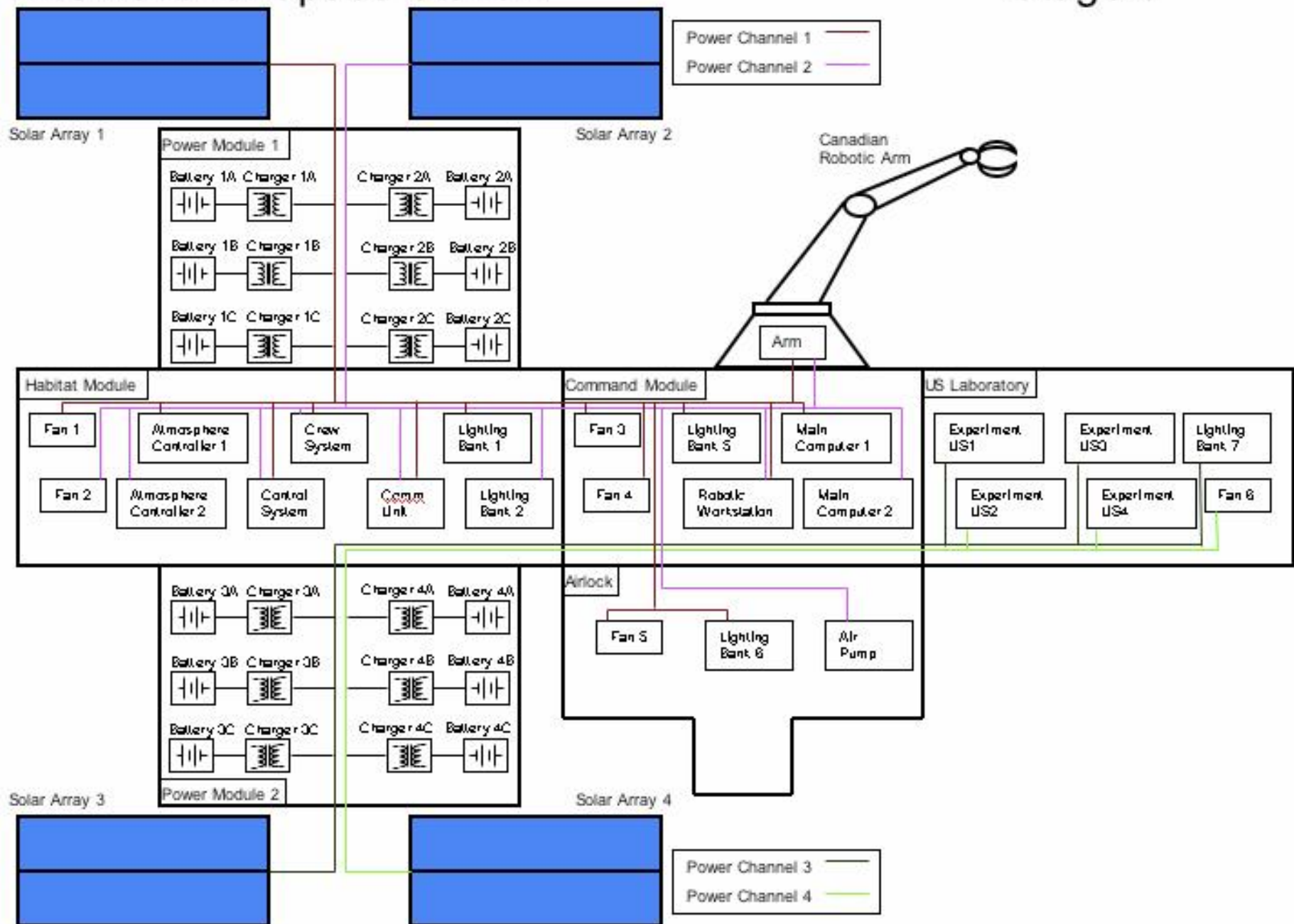
International Space Station

Stage 4



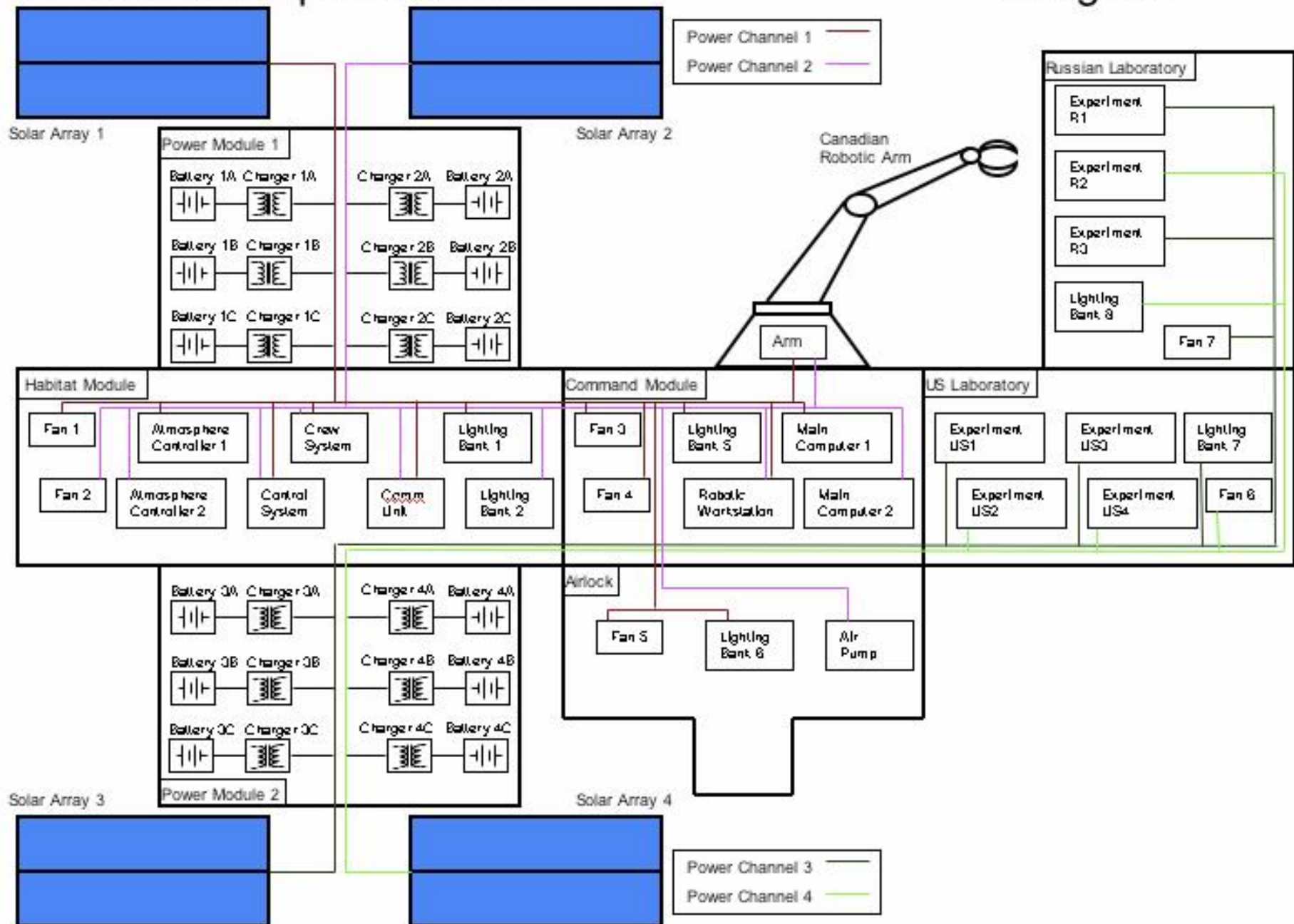
International Space Station

Stage 5

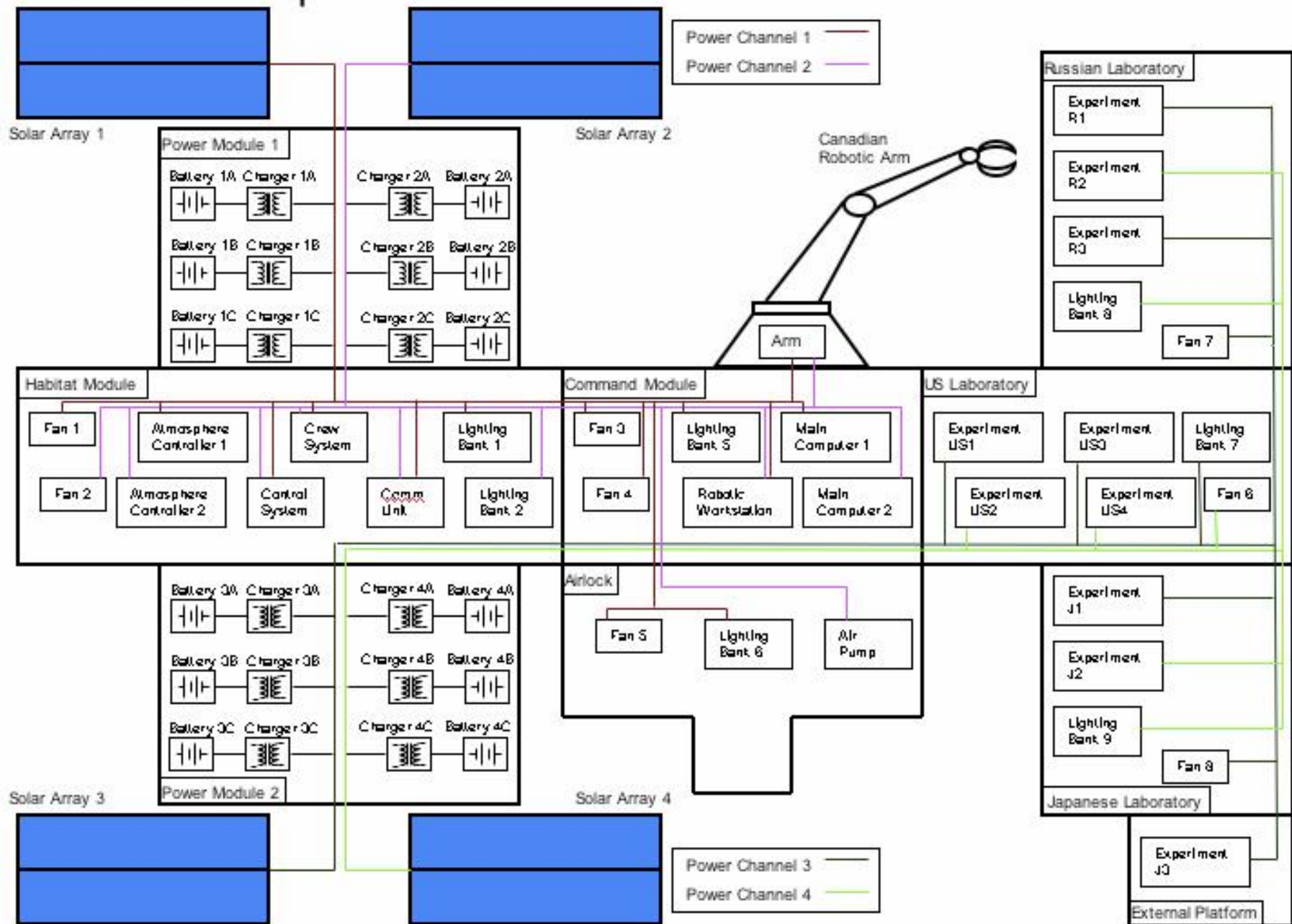


International Space Station

Stage 6



International Space Station



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